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# Investigating the concentration of radionuclides in wells used as drinking water in northern Nigeria. A case study of Jos metropolis

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The increasing health effects of nuclear radiation occasioned by the enhanced human activities in the environment necessitated the need for constant investigation and assessment of radiological impact on the general populace within a confined area. Based on this, Twenty two (22) (Hand dug and motorized) well water samples were collected from various locations distributed across Jos Metropolis, Jos North LGA, Plateau State, Nigeria and analyzed for the concentration activity of these radionuclides ($^{40}$K, $^{210}$Pb, $^{224}$Ra, $^{232}$Th, $^{238}$U) using radiochemical analysis technique, a high resolution gamma ray Spectrometry and a radon emanometry technique. The estimated mean concentration activity of $^{40}$K, $^{210}$Pb, $^{224}$Ra, $^{232}$Th and $^{238}$U in well water samples use as drinking water were determined. The mean concentration ranges from 1.36±0.51 Bq/l to 5.75±1.30 Bq/l. The mean concentration of $^{40}$K in well water samples ranges from 3.80±1.19 Bq/l to 2.05±0.30 Bq/l. The mean concentration of dissolved $^{224}$Ra in well water samples collected varies from 5.75±1.30 Bq/l to 1.95±0.58 Bq/l. $^{210}$Pb has an average concentration of 2.68 ± 0.80 Bq/l to 1.97±0.87 Bq/l. $^{232}$Th and $^{238}$U had average concentrations of 3.09 ± 0.57 Bq/l to 1.89±0.24 Bq/l and 5.41 ± 1.37 Bq/l to 1.36±0.51 Bq/l respectively. $^{210}$Pb and $^{224}$Ra were slightly above the recommended limits of 0.10 Bq/l and 1.00 Bq/l respectively, this can be attributed to the geological formation of the sampled area. $^{232}$Th and $^{238}$U where within the accepted standard limits of 1.00 Bq/l and 10.00 Bq/l recommended value by WHO (World Health Organization) and ICRP (International commission on radiological protection). Activity concentrations of measured radionuclides are in general decreasing in this order: $^{238}$U > $^{40}$K > $^{224}$Ra > $^{232}$Th > $^{210}$Pb for well water samples within Jos North LGA, respectively.

*Keywords: drinking water, radionuclides, NORMS Concentrations, well water.*

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## Introduction

Undoubtedly, one of the most fundamental necessities of life whose importance cannot be overemphasized is water. Being a vital ingredient for the sustenance of life on Earth, water meant for drinking and other domestic uses must therefore meet quality standards in order to be certified safe for human consumption. However, the availability of good quality water for drinking has been characterized with problems ranging from pollution to inadequate information to facilitate its exploitation for use [1]. Water is of major importance to all living things; in some organisms, up to 90% of their body weight comes from water. Up to 60% of the human adult body is water, and 71% of the planet surface is covered by water. The human brain and heart are composed of 73% water, and the lungs are about 83% water [2].

The ecological integrity of most water bearing bodies in the world, especially in developing countries like Nigeria, has been widely degraded and threatened because of human activities. Varying amount of radioactive materials, inorganic and organic contaminants have been released either directly or indirectly into water bearing bodies as products of human daily activities arising from industrial processes, municipal sewage discharge, agricultural practices and domestic wastewater, effluents, and atmospheric deposits [3]-[5]. The consequential health risks of radioactive nuclides and heavy metals contaminants in surface and underground water sources are issues that need special attention. This is more serious especially at levels where they exceed their prescribed safe limits for drinking water.

Given the huge contact with various types of rock deposits, minerals and ores with high concentrations of terrestrial radionuclides, consequently $^{226}$ Ra ( $^{238}$ U), $^{228}$Ra ( $^{232}$ Th) and their decay daughters and the single non-series $^{40}$ K are transported into water through leaching action [5]. The ingestion of water contaminated with radionuclides will result in irradiation of human internal organs by alpha, beta and gamma radiations [6]. Reports have shown that radionuclides present in water give clear information from which average radiation exposure from different sources can be estimated [7]. Studies have shown that different kinds of fatal cancers due to radon ingested from drinking water are equal to total lungs cancer due to inhalation of radon [8]. Continuous exposure to heavy metals and other chemical contaminants even at low levels could present a harmful effect to human health. Metals such as Cr, Ni, Cu, Fe, and Zn under the WHO/FAO set regulations are biologically significant. However, metals such as Hg, As, Cd, and Pb have no known biological or physiological importance in human systems and are therefore toxic even at low concentrations [9].

The study of radionuclide concentration in underground and spring water has been going on with great efforts in many countries of the world by many investigators [10]-[13]. Recently Vandenhove et al. [14] in part of their work reported on the radioactivity of

bore-hole water in their study area while Avwiri et al. reported the natural radionuclides in bore-hole water in Port-Harcourt in the oil rich Niger Delta of Nigeria [15].

While many developed nations of the world have set up agencies to regulate its water supply, it is not certain whether developing nations have toed this line [16]. There is need therefore to assess the concentration activities of radionuclides present in various water sources and ascertain whether this is above or below the minimum permissible dose due to exposure. The World Health Organization (WHO) and the United States Environmental Protection Agency (EPA) have issued regulations and guidelines on the quality of drinking water [17]. Water supply generally whether in the form of dug or drilled well is sourced from the soil, which is the product of weathering from the parent rock. The distribution of radionuclides in any water supply is a function of the local geology of the parent rock or soil [16, 17].

Investigation of the physical parameters and the total radioactivity concentrations carried out in some borehole water in Zaria, Northwestern Nigeria shows that some of the samples met the requirements of good water supply, while some had the alpha and beta radioactive concentrations above the set values recommended by the World Health Organization and the US Environmental Protection Agency (EPA) [18] also assessment of radionuclides concentrations in some public well water in Markudi Metropolis of Benue State, Nigeria using a Geiger Muller Counter shows variation is the concentration of radionuclides in the selected wells. It was reported that there exist highest radiation concentration in Borehole water ranging from $2.86 \times 10^{-1}$ Bq to $3.69 \times 10^{-1}$ Bq and the least in bottled water in the range $0.55 \times 10^{-1}$ – $0.77 \times 10^{-1}$ Bq. It is evident that physical contaminant in drinking water should not be under estimated as it poses a great risk to human health.

Uranium is a naturally-occurring radionuclide that decays over time and forms radium. Both elements are naturally present in rocks and soils. Radium breaks down further to form the radioactive gas radon. All three of these elements can dissolve in water, which means they can accumulate in wells. If the soil and rocks surrounding a well have high concentrations of radionuclides, the well water may contain a concentration level that exceed the EPA's standards.

When radionuclides are released to the environment, they persist until they are lost through radioactive decay, causing radiation exposures into the future [19]. Research has shown that access to safe drinking water is a prerequisite to poverty reduction [20]. Numerous diseases will be averted when ingested water is safe. Naturally occurring radionuclides in drinking-water are often less amenable to control [21]. Therefore, it is important to assess the concentration of radionuclides in our drinking water, so that remedial actions can be taken in order to minimize radiation risks.

Hand dug and motorized wells are the major sources of drinking water available and use by a large number of populace in major towns and cities of Nigeria. Hence, this work is intend to assess the level of physical contaminants and the concentration activities of these nuclides (i.e. radionuclides $^{40}K$, $^{210}Pb$, $^{224}Ra$, $^{232}Th$, $^{238}U$) present in Twenty two wells distributed across Jos North Local Government Area of Plateau State, North Central, Nigeria, using high resolution gamma ray Spectrometry.

## 1. Geological Setting

The Jos Plateau is a plateau located near the center of Nigeria. The plateau has given its name to the Plateau State in which it is found and is itself named for the state's capital, Jos. The plateau is home to people of diverse cultures and languages. The plateau's montane grasslands, savannas, and forests are home to communities of plants and animals distinct from those of the surrounding lowlands, and constitute the Jos Plateau forest-savannamosaic ecoregion [22].

It covers 8600 km$^2$ and is bounded by 300–600 m escarpments around much of its circumference. With an average altitude of 1280 m, it is the largest area over 1000 m in Nigeria, with a high point of 1829 m, in the Shere Hills. Several rivers have their sources on the plateau. The Kaduna River drains the western slopes, flowing southwest to join the Niger. The Gongola River drains eastwards to join the Benue. The Hadejia and Yobe rivers flow northeastwards into Lake Chad [23].

The Jos Plateau is dominated by three rock types. The older granites date to the late Cambrian and Ordovician. The younger granites are emplacements dating to the Jurassic, and form part of a series that includes the Aïr Massif in the central Sahara. There are also many volcanoes and sheets of basalt extruded since the Pliocene. The younger granites contain tin which was mined since the beginning of the 20th century, during and after the colonial period [24]. A map of Jos North is shown in Figure 1.

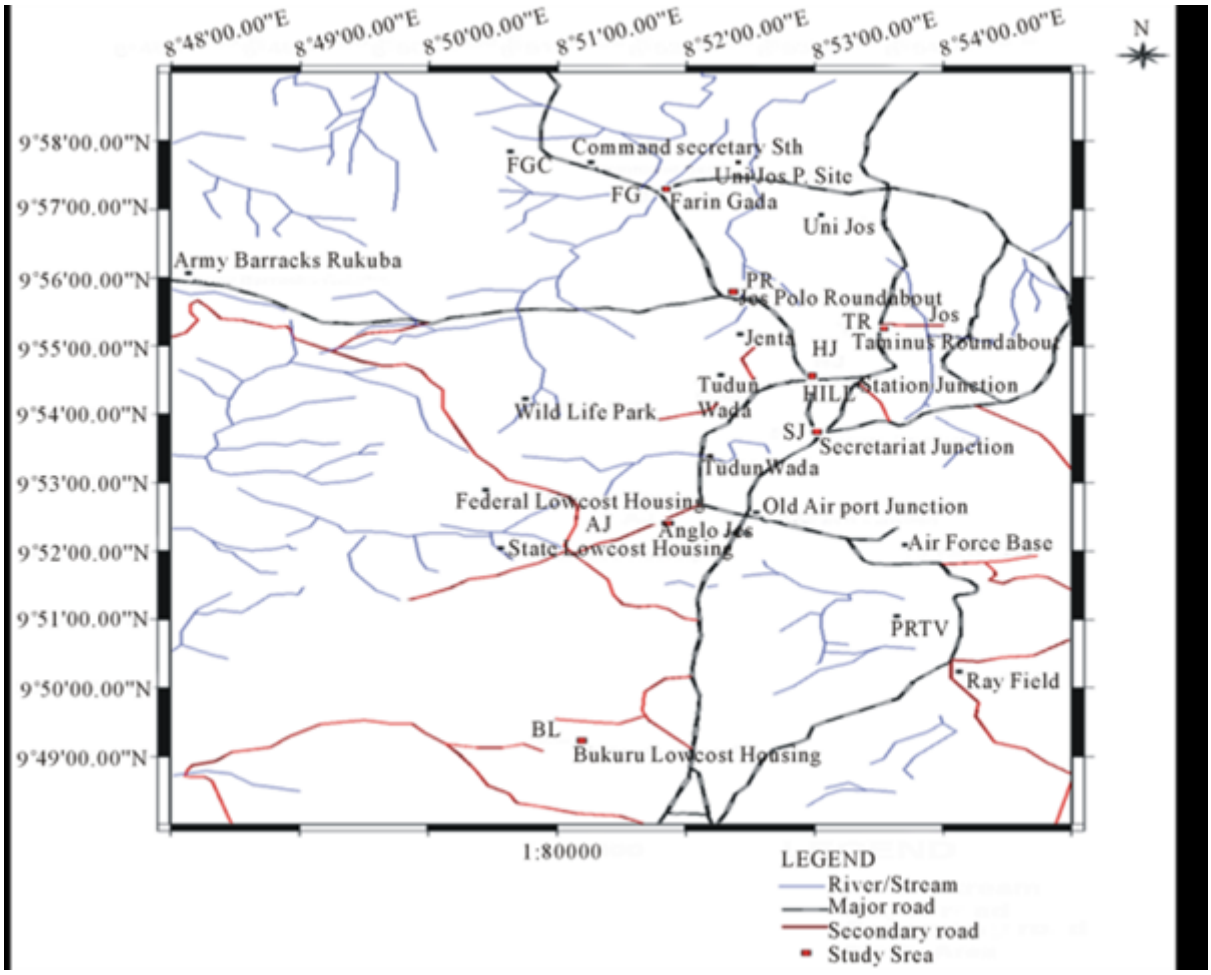


Fig. 1. A Map of Jos North

## 2. Materials and methods

### 2.1. Sample Collection and Preparation

Drinking water samples were collected from the selected well using very clean container [fetcher] whereby the usual manual procedure for collecting water from wells which involved the dipping of the containers which has been firmly tied to a rope long enough to reach the water level in the well was employed. Containers for the samples were washed with a solution of detergent and then rinsed with freshly distilled hydrochloric acid (HCl) to remove any inorganic material that might have stuck to the walls of the container before the samples were collected. The collected water was then emptied into a two litre keg and labeled based on the alphabet ascribed to each area and location. Water samples collected from the various dug and motorized wells across the metropolis using a two liter plastic keg were acidified with 11M of HCl at the rate of 10ml per liter of samples as soon as possible, to avoid absorption of radionuclide onto the wall of container. Marinelli beaker of 1L volume capacity previously washed, rinsed with a dilute sulphuric acid ($H_2SO_4$) and dried to avoid contamination was filled with sample from the container used for sampling. This was later sealed for at least four weeks to ensure that no loss of radon and to achieve secular equilibrium between the daughters and the parents nuclides [25].

*Table 1*

**Sampling points of well water samples in Jos-North L.G.A**

| | | | |
|---|---|---|---|
| Gada Biu | Kabong Village | Hand-dug | 40 |
| | Rukuba Road | Hand-dug | 35 |
| | Alheri | Hand-dug | 48 |
| | Jenta Adamu | Hand-dug | 38 |
| | Angwan Soya | Hand-dug | 30 |
| | Apata | Hand-dug | 25 |
| | Jenta Mangoro | Hand-dug | 45 |
| | Polo | Hand-dug | 42 |
| Army Barracks | Phase 1 | Motorized | 65 |
| | Phase 11 | Hand-dug | 40 |
| | Jebu | Hand-dug | 30 |
| | Car Wash | Hand-dug | 35 |
| | Mami | Motorized | 70 |
| Tudun Wada | Hill Station | Motorized | 65 |
| | Junction | | |
| | Tudun Wada | Hand-dug | 25 |
| | Secretariat | Motorized | 55 |
| | Fed. Low Cost | Motorized | 60 |
| | State Low Cost | Motorized | 50 |
| Old Airport | Old Airport | Motorized | 65 |
| | Rayfield | Motorized | 50 |
| | PRTV | Motorized | 65 |
| | Air Force Base | Motorized | 50 |

## 2.2. Measurements of activity concentration of radionuclide

The activity Concentrations of the dug and motorized well water samples were measured using an N-type coaxial HPGe gamma-ray detector at the laboratory of Nigeria Atomic Energy Commission, Abuja with ORTEC Multichannel Analyzer (MCA) and MAESTRO-32 evaluation software for spectrum acquisition and processing. The relative efficiency of the detector was 28.5 % with energy resolution of 1.8 keV at gamma ray energy of 1332 keV of $^{60}$Co. The gamma lines 609.31 and 1764.49 keV of $^{214}$Bi were used to determine $^{226}$Ra. The gamma lines 583.19 of $^{208}$Tl were used to determine $^{232}$Th and that of $^{40}$K was determined from the gamma line of 1460.83 keV. The samples were counted for 18.000 seconds (5 hours). The energy and efficiency calibrations were performed using mixed radionuclide calibration standard in the form of solid water, serial number NW 146 A with approximate volume 1000 mL and density 1.0 gcm$^{-3}$ in a 1.0 L Marinelli beaker. The standard was supplied by Deutscher Kalibrierdienst (DKD-3), QSA Global GmBH, Germany. Background measurements were made for the same period. Density corrections were also made where appropriate.

The specific activity concentrations (Asp) of $^{226}$Ra, $^{232}$Th, $^{238}$U,$^{210}$Pb and $^{40}$K were determined in Bq/l for the drinking water samples using the following expression [26]-[28] after decay correction.

## 3. Radium in water

Radium in water is analysed using radon emanometry technique. In the present study water sample of 20 L is collected in the polythene air tight prewashed container to analyse radium concentration in water. The samples were acidified with $HNO_3$ to avoid the adsorption of the actinides on the walls of the container. The water samples were filtered using whatman 42 filter paper in order to remove the soil and dust particles in it [29].

The water sample was co-precipitated with $MnO_2$, then pre-concentrated by evaporation and chemical method to estimate the activity of $^{226}$Ra. Pre-concentrated samples of about 70 ml was transferred into the radon bubbler to build up radon initially. The radon in the solution is removed with the help of a low suction pump. The schematic diagram of radon bubbler is shown Fig. 2.

After aeration is complete the bubbler is sealed and allowed for radon to build up and accumulate in the solution [30]. The buildup period is determined by the expected radium content and is generally about 7 half-life of radon which is about 21 days. The accumulated radon is transferred to evacuated scintillation cell (150 cm$^3$). This is connected to a radon bubbler through rubber tubing, which was well sealed from atmosphere. On agitating the water in the bubbler the dissolved radon gets desorbed and enters into the scintillation cell by vacuum transfer. Alpha activity of the scintillation cell was counted using alpha probe and counting system specially designed for this purpose. Total radium dissolved in the solution taken is given by $^{226}\text{Ra}=6.97\times10^{-2}\times \text{DV}\times\text{E}\times(\exp(-\lambda T)\times(1-\exp(-\lambda\theta))\times(1-\exp(-\lambda t))$. Where D – counts above background, V — volume of water, E – efficiency of the scintillation cell (74%), $\lambda$ — decay constant for radon ($2.098 \times 10^{-6}$ s$^{-1}$), $T$ — counting delay after sampling, $t$ — counting duration, $\theta$ — build up time in the bubbler Polonium in water.

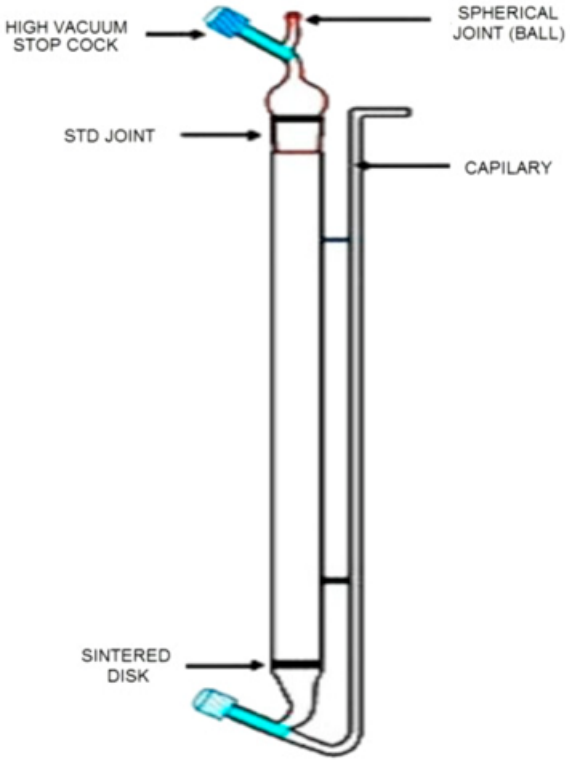


Fig. 2. Schematic diagram of Bubbler

## 4. Sampling procedure

Drinking water samples collected from Jos North Local Government Area were analysed for the activity of $^{210}$Po using radiochemical analysis technique. About 20 L of water is collected inside a pre cleaned plastic can, using distilled water. Water is filtered using whatman 42 filter paper. The pH of the water is determined. HCl is added such that the pH of water is maintained to 2.0. Further iron carriers are added and stirred for about 30 min. Ammonia solution is added to make the pH equal to 9. Then thick ferric hydroxide precipitate is formed. This precipitate is dissolved using 0.5 N HCl and the sample is ready for processing [31].

## 5. Sample Processing

The sample is taken in a beaker and placed on a hot plate cum magnetic stirrer and stirred for 6 h. A silver disc is inserted inside the solution during this procedure. This process is called electrodeposition method. In this procedure 99% of $^{210}$Po gets deposited on silver disc. Then after 6 h of heating for about 80 °C the silver disc is removed washed using distilled water, ethanol and dried in infrared light [32]. The formula used to calculate $^{210}$Po in water is as follows: $A = (S) \times (100 \times 100 \times 1000)(\varepsilon \times Ep \times W)$. Where A — activity in mBq/l, S — background subtracted sample counts per sec, $\varepsilon$ — efficiency of alpha counting system, $E_p$ — plating efficiency (99%), W — Mass of the sample taken for analysis.

## 6. Health risk assessment

The annual effective dose (AED) due to ingestion of $^{238}$ U, $^{232}$Th and $^{40}$ K in drinking water was estimated in order to evaluate the radiological hazards of the Jos North area. The AED in $mSvy^{-1}$ was estimated using the activity concentrations of the radionuclides according to the relation [33]. AED = Ac×Cf ×CRw. Where Ac is the activity concentration of the radionuclides $^{238}$ U, $^{232}$Th and $^{40}$K (Bq/l), Cf is the dose conversion factors for radionuclides, which is age dependent. CRw is the consumption rate of drinking water. The conversion factors used in arriving at the AED were taken from ICRP [32, 33] while the annual consumption rate of water for the different age groups was extracted from the publication of World Health Organization (WHO) [34].

## 7. Results and discussions

*Table 2*

**Activity concentration of radionuclides in the water samples (Bq/l) around Gada Biu**

| Sampling Areas | pH | $^{40}$K | $^{210}$Pb | $^{224}$Ra | $^{232}$Th | $^{238}$U |
|---|---|---|---|---|---|---|
| Kabong Village | 8.2 | 4.09±1.01 | 2.07±0.82 | 7.12±1.17 | 3.32±0.62 | 7.21±1.34 |
| Rukuba Road | 8.5 | 6.11±1.74 | 4.18±1.22 | 9.01±1.81 | 5.19±1.50 | 9.81±2.09 |
| Alheri | 7.3 | 5.52±1.56 | 3.08±0.63 | 8.63±1.70 | 4.20±1.12 | 7.98±1.60 |
| Jenta Adamu | 6.4 | 3.16±0.29 | 2.02±0.81 | 5.04±0.84 | 2.18±0.87 | 4.96±0.68 |
| Angwan Soya | 6.1 | 1.23±1.01 | 2.93±0.50 | 4.11±1.28 | 0.96±0.18 | 1.71±0.21 |
| Apata | 6.2 | 1.35±1.31 | 1.07±0.26 | 2.09±1.91 | 0.71±0.16 | 0.92±0.19 |
| Polo | 6.5 | 3.94±0.91 | 3.02±0.58 | 4.92±0.91 | 2.96±0.14 | 5.72±0.55 |
| Mean Value | 7.1 | 3.80±1.19 | 2.68±0.80 | 5.75±1.30 | 2.94±0.99 | 5.41±1.37 |
| WHO Limits | | NE | 0.10 | 1.00 | 1.00 | 10.00 |

*Table 3*

**Activity concentration of radionuclides in the water samples (Bq/l) around Army Barracks**

| Sampling Areas | pH | $^{40}$K | $^{210}$Pb | $^{224}$Ra | $^{232}$Th | $^{238}$U |
|---|---|---|---|---|---|---|
| Phase I | 7.6 | 4.19±0.90 | 2.93±0.67 | 5.71±1.34 | 3.51 ±0.36 | 6.07±1.64 |
| Phase II | 7.5 | 4.03±0.81 | 2.19±1.09 | 4.98±1.27 | 3.08±0.55 | 5.18±1.34 |
| Jebu | 6.9 | 3.90±0.72 | 1.23±0.47 | 4.07±0.83 | 2.98±0.63 | 4.91±1.24 |
| Car Wash | 6.4 | 1.79±1.26 | 2.94±0.66 | 2.65±0.79 | 2.90±0.69 | 3.83±0.67 |
| Mami | 6.7 | 3.01±0.61 | 3.06±0.57 | 4.95±1.25 | 2.97±0.64 | 3.02±0.60 |
| Mean Value | 7.02 | 3.38±0.86 | 2.47±0.89 | 4.47±1.10 | 3.09±0.57 | 4.60±1.10 |
| WHO Limits | | NE | 0.10 | 1.00 | 1.00 | 10.00 |

The results of activity concentration of radionuclides in the water samples (Bq/l) around Gada Biu area as shown in Table 1. The recorded value of $^{40}$K ranges from 6.11±0.91 Bq/l with an average of 3.80±1.19 Bq/l. Rukuba Road recorded a much higher concentration of 6.11±1.74 Bq/l. While Angwan Soya recorded a lower concentration

*Table 4*

**Activity concentration of radionuclides in the water samples (Bq/l) around Tudun Wada**

| Sampling Areas | pH | $^{40}$K | $^{210}$ Pb | $^{224}$Ra | $^{232}$Th | $^{238}$U |
|---|---|---|---|---|---|---|
| Hill/S Junction | 7.1 | 4.21±1.32 | 3.11±1.07 | 4.63±1.47 | 3.05±0.76 | 2.97±0.70 |
| Tudun Wada | 6.7 | 3.92±1.20 | 2.87±0.95 | 3.08±0.78 | 2.67±0.44 | 2.04±0.66 |
| Secretariat | 6.5 | 1.93±0.74 | 1.02±0.98 | 2.09±0.63 | 1.06±0.21 | 1.91±0.76 |
| Fed. Low Cost | 6.4 | 1.24±1.11 | 1.83±0.37 | 1.97±0.71 | 2.01±0.69 | 1.23±1.12 |
| State Low Cost | 6.3 | 1.09±0.29 | 1.03±0.97 | 1.91±0.76 | 1.67±0.90 | 1.21±1.13 |
| Mean Value | 6.6 | 2.48±1.11 | 1.97±0.87 | 2.74±0.87 | 2.09±0.80 | 1.87±0.87 |
| WHO Limits | | NE | 0.10 | 1.00 | 1.00 | 10.00 |

*Table 5*

**Activity concentration of radionuclides in the water samples (Bq/l) around Old Airport**

| Sampling Areas | pH | $^{40}$K | $^{210}$ Pb | $^{224}$Ra | $^{232}$Th | $^{238}$U |
|---|---|---|---|---|---|---|
| Old Airport | 6.4 | 1.96±0.30 | 1.94±0.27 | 1.08±0.93 | 1.80±0.30 | 1.10±0.51 |
| Rayfield | 6.5 | 2.09±0.20 | 2.10±0.30 | 1.90±0.22 | 2.01±0.35 | 1.40±0.20 |
| PRTV | 6.6 | 2.19±0.37 | 1.92±0.30 | 2.90±0.98 | 1.86±0.17 | 1.92±0.75 |
| Airforce Base | 6.5 | 1.95±0.32 | 2.06±0.22 | 1.91±0.20 | 1.87±0.14 | 1.03±0.58 |
| Mean Value | 6.5 | 2.05±0.30 | 2.00±0.27 | 1.95±0.58 | 1.89±0.24 | 1.36±0.51 |
| WHO Limits | | NE | 0.10 | 1.00 | 1.00 | 10.00 |

of 1.23±1.36 Bq/l. The presence of $^{40}$K in drinking water samples around Gada Biu area shows its availability in nature. Research has shown that $^{40}$K represents 0.012% of naturally occurring potassium that is found in large quantity throughout nature. Though homeostatically controlled in the body, its decay mechanism is associated with cell damage and renders it potent for cancer induction. Lifetime cancer mortality risk due to its ingestion is estimated as $2.2\times10^{-11}$ pCu$^{-1}$ [35]. These recorded values of $^{40}$K recorded around Gada Biu area is considered low compared with values obtained around the world [36].

The dissolved radium concentration is 9.01±0.80 Bq/l with an average of 5.75±1.30 Bq/l. The highest concentration of $^{224}$Ra in this study is observed at Rukuba Road and Kabong village. This is due to a volcano-sedimentary sequence which was probably not repeated in subsequent geological periods. The quartzites of the Sargur group are mature sandstones and these rocks have relatively higher concentration of $^{224}$Ra [37].

The specific levels of radium radioactivity are related to the types of rock from which the soils originate. Higher radiation levels are associated with igneous rocks, such as granite, and lower levels with sedimentary rocks. There are exceptions however, as some shales and phosphate rocks have relatively high content of radionuclides [38]. The contribution to the effective dose from the natural bore well water is less than the contribution from inhalation of radon emanating from the well water.

It was noted that in all samples, concentrations of $^{238}$ U were higher than those of $^{232}$ Th. This observation might be due to the presence of uranium-bearing minerals associated with granite rocks together with limestone commonly found in Gada Biu and nearby villages. The wide variation in activity concentrations observed can also

be attributed to differences in radionuclides solubility and mobility. However, the mean value of $^{238}$U was below the permissible limit of 10.00 Bq/l, but also lower compared to research carried out at Islamabad, Pakistan and Burutu, Nigeria with mean values of 11.3 ± 2.3 Bq/l and 14.51 ±1.69 Bq/l respectively.

Table 2: The mean activity concentrations of $^{40}$K and $^{238}$U obtained in this present study were significantly higher than UNSCEAR and WHO world average limits of 10.0 and 1.0 Bq/l respectively for drinking water. That of $^{232}$Th (2.94 ± 0.99 Bq/l) is slightly higher than the limit of 0.1 Bq/l. This clearly indicates that the surface water of Army Barracks is radiologically contaminated and not safe for drinking. From the radiological point of view, the accumulation of radionuclides $^{238}$U, $^{232}$ Th and $^{40}$ K due to ingestion of water from Army Barracks could present a low dose radiological risk of longer term effects [39] to the health status of the Army Barracks people. When ingested, the radionuclides undergo radioactive decay, releasing in the process ionizing radiation. The human internal organs are therefore subjected to continuous irradiation which can lead to various radiation induced diseases. This situation therefore calls for urgent steps in ensuring that water purification plants are installed in the community and potable water made available to the people. When compared with other studies from some parts of the world (Table 5), it was found that the mean activity concentration of $^{40}$ K and $^{238}$ U was greater than those observed in water samples from Port Harcourt, Nigeria; Kuala Lumpur and Makkah, Saudi Arabia. The activity of $^{238}$ U was lower than that observed in surface water from Osun, Nigeria. The mean activity of $^{232}$ Th (2.94 ± 0.99 Bq/l) was lower than those found in some of these locations except for the value 0.12 Bq/l and 0.41 ±0.02 Bq/l observed in drinking water from Saudi Arabia and Bomaa, Ghana respectively.

*Source:F.O. Ugbede, B.C. Aduo and O.N. Ogbonna et al. Natural radionuclides, heavy metals and health risk assessment in surface water of Nkalagu river dam with statistical analysis. Scientific African.* ***8*** *(2020), e00439*

The concentration activities of $^{238}$U, $^{224}$Ra, $^{210}$Pb, $^{232}$Th, and $^{40}$K measured in the samples are presented in Table 3. The possible sources of radionuclide contaminants of water samples from the boreholes are uncertain and may be due to natural processes. The mean activity of $^{40}$K, $^{232}$Th, and $^{238}$U are 0.14 ±0.01 Bq/l, 3.98±0.26, 11.00±2.58, and 17.73±5.04 Bq/l, respectively. The concentration of $^{238}$U 1.87±0.87 was below the guidance level in all the water sampled but for Tudun Wada area. However, the activity concentrations of $^{210}$Pb, $^{224}$Ra and $^{232}$Th are above the guidance level in all samples except for secretariat area. The Guidance Level (GL) was adopted from the (WHO, 2011) water quality guidelines.This same results can also be seen in Kulim, Malaysia and Port Harcourt, Nigeria (F.O. Ugbede, B.C. Aduo and O.N. Ogbonna et al. / Scientific African 8 (2020)). Guidance level was not established for $^{40}$K.

The concentration activities of $^{238}$U, $^{224}$Ra, $^{210}$Pb, $^{232}$Th, and $^{40}$K measured in the samples are presented in Table 4.

The activity concentrations were found to be within the range 1.80±0.30 to 2.94±0.99 Bq/l $^{232}$Th, 1.95±0.32 to 2.19± 0.37 Bq/l $^{40}$K, and 1.08±0.93 to 2.90±0.98 Bq/l $^{226}$Ra for Old Airport area. While $^{238}$U and $^{210}$Pb in well water samples lie within the range 1.03±0.58 to 5.41±1.37 Bq/l and 1.92±0.30 to 2.10± 0.30 Bq/l respectively. $^{238}$U had the highest concentration, followed by $^{226}$Ra and the least activity was found in $^{210}$Pb. The highest activity concentration of the three radionuclides ($^{238}$U, $^{226}$Ra and $^{210}$Pb was recorded in the sample taken from PRTV and the least was found in the sample taken from Airforce Base with the exception of Rayfield that had the highest

*Table 6*

**Comparison of specific Activity of$^{238}$ U, $^{232}$ Th,$^{226}$Ra and$^{40}$ K with other studies from different parts of the world**

| Sampling Areas | SOURCE | $^{238}$U/$^{226}$Ra | $^{232}$Th | $^{40}$K |
|---|---|---|---|---|
| Islamabad Pakistan | Bottled Water | 11.3 ± 2.3 mBq/l | 5.2±0.9 mBq/l | 140.9±30.6 mBq/l |
| Kulim Malaysia | Well | 3.46 mBq/l | 2.71 mBq/l | 186.3 mBq/l |
| Port Harcourt Nigeria | Borehole | 3.51±1.22 Bq/l | 2.04 ±0.29 Bq/l | 23.03±4.37 Bq/l |
| Osun Nigeria | Surface Water | 8.165 ±2.05 Bq/l | 5.24 ±1.57 Bq/l | 61.015 ±15.5 Bq/l |
| Kuala Lumpur | Surface Water | 2.8±0.4 Bq/l | 1.2±0.4 Bq/l | 35.1±4.2 Bq/l |
| Makkah Saudi Arabia | Underground Water | 0.558 Bq/l | 0.204 Bq/l | 4.581 Bq/l |
| Saudi Arabia | Drinking Water | 0.32 Bq/l | 0.12 Bq/l | 10.96 Bq/l |
| Bomaa Ghana | Well | 0.38±0.02 Bq/l | 0.41±0.02 Bq/l | 4.24±0.32 Bq/l |
| Burutu Nigeria | Surface Water | 14.51±1.69 Bq/l | 26.90±7.27 Bq/l | 61.55±4.17 Bq/l |
| Elba Egypt | Natural Water | 1.6-0.97 Bq/l | 0.21–1.1 Bq/l | 9.7-23.0 Bq/l |
| Nkalagu Nigeria | Surface Water | 5.49±0.70 Bq/l | 0.14±0.01 Bq/l | 120.45±6.51 Bq/l |

activity concentration for $^{210}$Pb. The result obtained in both cases for $^{226}$Ra exceeds the recommended limits of 1.00 Bq/l [40]. This result corroborates the recordings from Nkalagu, Nigeria and Burutu, Nigeria 5.49±0.70 Bq/l and 14.51 ±1.69 Bq/l respectively reported in other part of the world and for $^{226}$Ra by [40] in private dug well in Akure Southwestern Nigeria.

## Conclusion

Water is vital to the total well-being of man, hence it is expected that it meets quality standards in order to be certified safe for human drinking. This work presents the first detailed assessment of the activity concentrations of $^{40}$K, $^{210}$Pb, $^{224}$Ra, $^{232}$Th and $^{238}$U were measured in drinking waters from wells and boreholes of Jos-North Local Government Area of Plateau State using gamma spectrometry. The activity concentrations of $^{40}$K, $^{210}$Pb, $^{224}$Ra, $^{232}$Th and $^{238}$U in the dug well and boreholes water samples distributed across four zones with twenty two sampled areas had been determined and compare well with known literature values. The activity concentration of gamma emitters in dug and drilled well water ranged from 1.09±0.29 to 6.11±1.74 Bq/l $^{40}$K, 1.02±0.98 to 4.18±1.22 Bq/l $^{210}$Pb, 1.08±0.93 to 9.01±1.81 Bq/l $^{224}$Ra, 0.71± 0.16

to 5.19±1.50 Bq/l $^{232}$Th, and 0.92±0.19 to 9.81± 2.09 Bq/l $^{238}$U respectively. These mean activities exceeded the World Health Organization recommended guidance level in all the water samples of this study for $^{210}$Pb, $^{224}$Ra and $^{232}$Th. This is a sole reflection of radiological contaminated surface and underground water and further consumption could be detrimental to the well-being of Jos North residents.

**Competing interests.** The authors declare that there are no conflicts of interest regarding authorship and publication.

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# Исследование концентрации радионуклидов в колодцах, используемых в качестве питьевой воды в северной Нигерии. На примере мегаполиса Джос

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Растущее воздействие ядерной радиации на здоровье, вызванное усилением деятельности человека в окружающей среде, обусловило необходимость постоянного исследования и оценки радиологического воздействия на население в пределах ограниченной территории. Было отобрано двадцать два образца колодезной воды из различных мест, распределенных по мегаполису Джос, Нигерия, и проанализированы на активность радионуклидов ($^{40}$K, $^{210}$Pb, $^{224}$Ra, $^{232}$Th, $^{238}$U) с использованием метода радиохимического анализа, гамма-спектрометрии высокого разрешения и метода радоновой эманометрии. Определены средние концентрации радионуклидов в образцах воды из скважин, используемых в качестве питьевой воды. Средняя концентрация $^{40}$K колеблется от 3,80±1,19 Бк/л до 2,05±0,30 Бк/л. Средняя концентрация $^{224}$Ra варьируется от 5,75±1,30 Бк/л до 1,95±0,58 Бк/л. $^{210}$Pb от 2,68±0,80 Бк/л до 1,97±0,87 Бк/л. $^{232}$Th и $^{238}$U имели средние концентрации от 3,09±0,57 Бк/л до 1,89±0,24 Бк/л и от 5,41±1,37 Бк/л до 1,36±0,51 Бк/л. $^{210}$Pb и $^{224}$Ra были немного выше рекомендуемых пределов 0,10 Бк/л и 1,00 Бк/л, это может быть связано с геологическим строением отобранной области. $^{232}$Th и $^{238}$U находились в пределах принятых стандартных пределов 1,00 Бк/л и 10,00 Бк/л, рекомендованных ВОЗ и МКРЗ.

*Ключевые слова: колодезная питьевая вода, активность, Нигерия*

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